Long-Range Radio Tracking of Sea Turtles and Polar Bear—Instrumentation and Preliminary Results[1]

HOWARD A. BALDWIN
Sensory System Laboratory
and
The University of Arizona

THIS PAPER describes instrumentation developed for studies of path behavior of the green sea turtle (*Chelonia mydas*) and migration movement of polar bear (*Thalarctos maritimus*) and gives preliminary results bearing on navigation ability in these species. Both species operate in difficult environments, and the problems faced in the design of electronic instrumentation for these studies are not completely specified at this time. However, the critical factors yet to be understood are primarily related to the behavior of instrumented animals.

Both telemetry systems are intended to provide tracking data at ranges of approximately 185 km (100 nm). The application of waveguide techniques to UHF antennas (ref. 1) has resulted in an efficient omnidirectional antenna approximately 2.5 cm in height for use with polar bear. A desirable feature is the packaging that allows all electronic components to be embedded compactly in plastic for both mechanical protection and immersion in salt water. The marine turtle instrumentation incorporates telemetry of directional and velocity data at periodic intervals. This feature frees the experiments from the need to maintain bearing data from known geographic locations to reconstruct movement patterns of instrumented turtles at sea. This feature is particularly valuable for studies involving the testing of navigation ability under experimental constraints.

The data obtained with these experimental techniques are included in this report, first to illustrate the technique and, second to provide initial preliminary results bearing on animal navigation.

TURTLE INSTRUMENTATION

Marine turtle radio tracking experiments have been underway for about 3 years. A

[1] Studies of the green sea turtle are in collaboration with Archie Carr, University of Florida, and the polar bear studies are in collaboration with Jack W. Lentfer, Alaska Department of Fish and Game. Donald L. Brumbaugh contributed electronic instrumentation design, and Dale E. Hall mechanical design. Both are members of the Sensory Systems Laboratory.

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radio frequency was selected in the HF band allocated for unattended buoy operation by the Federal Communications Commission. Narrowband, low-power operation at 8 MHZ was found to be satisfactory for ground or sky wave propagation over sea water at ranges on the order of 185 km (100 nm). Reception is available periodically at increased ranges, depending upon ionospheric conditions. In the summer of 1967 a tracking experiment was initiated at Tortuguero, Costa Rica, using a periodically transmitted cw signal and dual phase locked receivers (ref. 2). Two vertical antennas spaced one half wavelength apart provided an azimuth track of the float position from the launching point of the turtle. After approximately 1 hour and 20 minutes, sharks were observed near the float and the signal disappeared. The experiment and subsequent discussion provided two significant conclusions: (1) Telemetry equipment would have to withstand shark attack, and (2) path behavior (that is, periodic transmission of turtle heading and swimming speed from the float) would be more valuable than geographic position in understanding the factors that provide orientation to a migrating turtle.

During the later part of the nesting season in October 1968, a second attempt was made to track a turtle at Tortuguero. The instrumentation contained the following:

(1) A float consisting of a sealed aluminum pipe 12.7 cm in diameter, 2 meters in length, balanced with a keel to support a vertical whip antenna.

(2) A wand type velocity probe whose deflection due to relative movement between the float and the water was sensed with a linear differential transformer.

(3) A spinning magnetometer consisting of a moving coil for sensing the earth's magnetic field for directional bearings.

(4) Timing, logic and coding to key a transmitter with pulse-time cw modulation at 20-minute intervals.

(5) An 8 MHZ tranmitter providing approximately 1-watt input to a loaded vertical whip antenna. A long-life battery pack was provided.

At 1020 hours on September 29, 1968, the float was attached to a mature female turtle and launched. The line between the turtle and the instrumentation float was 21 meters in length—considered to be sufficient for a float to remain at the surface during the migration from the nesting beach to one of the various feeding grounds located throughout the Caribbean. A piece of iron wire was used in the attachment to provide an automatic release mechanism for the turtle after several weeks.

Tracking data were obtained during the subsequent 4 days and are summarized as follows:

For the first 6 hours the turtle headed generally away from the shoreline and then turned north in the afternoon. Heading and swimming speed data indicated that she turned toward shore during the night. The heading suggested that the current at the mouth of the Tortuguero River and along the coast was responsible for the apparent velocity and direction data recorded. The currents along this coast are induced as a backwash of the Gulf Stream, and it was necessary to assume an average rate of water movement of 0.496 km (0.3 mile) per hour to the southeast along the shoreline to provide correlation between visual sightings of the float and integrated movement vectors from telemetered data.

A visual determination of the float position was made at 0608 hours on the morning of the second day, September 30. The turtle continued a northwesterly heading until 0806 hours. The investigators approached the instrument float in a small boat at 1026 hours

and as soon as it was touched the turtle sounded, taking the float under the surface at a steep angle. It resurfaced in about 15 meters, and no further attempt was made to physically contact the float. In the afternoon at 1647 hours, signals were interrupted by radio interference and radio contact was not reestablished until 0555 hours the morning of the third day. During the night the interference decreased and signals from the float were still not available. There is considerable likelihood that the turtle submerged and rested during the night at a depth sufficient to take the instruments below the surface.

Bearing and velocity data resumed at 0555 hours and continued throughout the third day and night. There is a suggestion that turtle swimming inactivity in the early morning hours on the morning of the fourth day can be inferred from the bearing data.

Bearing and velocity data were received until 1518 hours, October 2, the fourth day after release. At that time the transmitter signal was heard continually without data modulation for the following 3 days. This indicated a malfunction in the programming circuits that would have caused a rapid dissipation of battery power. The instrument float was recovered on the beach October 14, 16.7 km north of the release point.

The following information was considered pertinent from this work with regard to the design of future experiments:

(1) The heading data gave a reasonable picture of path behavior with regard to navigation ability. Headings were generally consistent and inferred that a single prevailing direction was maintained. The absence of a dispersion or randomness to heading data tends to weaken an hypothesis dependent on sampling for olfactory cues. On the other hand, the importance of the abundant clues for guidance available from the coastline in terms of wave noise, salinity changes, water depth and others would make it quite possible for the turtle to maintain a reasonably constant heading parallel to the coast.

(2) The weakness of the data lies in that it provided no reference to geography once the float was not visible. The magnitude of the Gulf Stream countercurrent was unsuspected at inception of the experiment. Velocity data were unreliable for two reasons: (a) the vertical movement of the tethered float in waves was found to create an error in apparent speed, and while the error was small compared to the swimming velocity, it was cumulative; and (b) the strong currents in the waters near the coast tended to override the velocity information sensed at the float. In one case the velocity data showed the turtle proceeding to the north when, in fact, the float was observed being carried to the south. This discrepancy was particularly evident at night when the turtle appeared to rest.

The data lost due to radio interference on the short wave frequencies amounted to 5.5 percent of the data transmitted, if we assume that the float was submerged the second night after release. Interference occurred primarily at night when the conditions for skip or ionospheric propagation modes occur. The following conclusions were made:

(1) Future experiments using telemetry would require a direction-finding system in addition to vector movement data, particularly when studies occurred close to land.

(2) The velocity sensor based on deflection of a probe should be abandoned in favor of an ultrasonic system.

(3) The float would have to be submergible.

Preparations for the third attempt to track *Chelonia* during its migration (this time at Ascension Island in the mid-Atlantic) were begun soon after the work at Tortuguero. Design concepts included:

(1) A velocity sensor based on detection

of Doppler shift by ultrasound. Ultrasonic energy is beamed into the water and the backscattered energy is detected and analyzed. Relative movement between the sensor and the water is detected as a frequency shift between the generated energy and the scattered energy. The unit was tested extensively and found to operate in the Gulf of California and in several lakes. It was noted, however, that pure water did not provide sufficient scattering to give a detectable signal. A few particles from 1 to 10 microns in cross section did provide an adequate signal.

(2) Loop antennas were designed for direction finding bearing accuracies of $\pm 1/4°$ at ranges of 18.5 km (10 nm), and $\pm 5°$ at ranges of 185 km (100 nm).

(3) Transmissions occurred at 10- rather than 20-min intervals.

(4) All electronic subassemblies were hermetically sealed in aluminum canisters designed to withstand submersion.

(5) Four floats were prepared for the Ascension Island tests. All were to transmit on the same frequency and if used simultaneously, they were to be distinguished by the time of transmission. The clock mechanism was electromechanical so that reference to standard time could be maintained.

When the instrumented floats arrived at Ascension Island they were found to have been damaged in shipment. All of the compass shafts were broken, indicating that the floats had sustained high impact forces. The instruments were repaired or redesigned as well as possible, calibrated, and tested extensively.

On April 7, 1969, an instrumented turtle weighing some 300 kg was transported 187 km (101 nm) north-northwest of Ascension Island and released. Data transmissions were received for the next 2 hours and then abruptly terminated. Heading data were remarkably constant and indicated a bearing almost directly towards Ascension Island; velocity data were not present in the transmission. We have assumed that the lack of particulate matter in the ocean reduced the backscattered energy below detectable limits.

There were no clues as to the cause of cessation of signals from the float. The float was not recovered at Ascension Island and no facilities were available to inspect the area from which the last transmission was made. Conjecture runs as follows:

(1) The turtle submerged to unexpected depths. No information is available as to the maximum diving capability of this species.

(2) There is a small but finite possibility of physical interference with the experiment.

(3) Failure of electronic components could have occurred.

(4) Large sharks are frequently observed in the water adjacent to the island, and shark interference is possible.

Tests were continued in the summer of 1970 at Tortuguero, Costa Rica. The equipment used is basically that given in the Appendix, with the following exceptions:

(1) The velocity indicator is a commercially available "paddlewheel" type[2]. The paddlewheel contains small magnets that provide four impulses per revolution. These impulses are stored in a capacitor memory and translated to a pulse code in such a way that velocity is given by counting the number of transmitted pulses.

(2) While the spinning coil magnetometer was reliable in use, it was desirable to eliminate the mechanical problems of the moving coil, together with the power consumption of a small motor. A miniature two-axis fluxgate magnetometer designed and described by C. J. Pellerin and M. H. Acuna (ref. 3) was employed.

[2] Signet Scientific Co., Burbank, California, "Knotmeter."

(3) The float was reduced in size and provided with a lead keel mounted close to the float body to allow the antenna to maintain approximately 45° inclination to a flat surface. If the float were to be detached from a turtle and drift to a beach, it would be desirable to receive a directional signal from the float.

The following specifications apply to the 1970 float design shown in figure 1:

Length:	approximately 1 m
Diameter of body:	15 cm
Antenna length:	2.9 m
Weight in air:	9.3 kg
Balance:	The keel provides twice the righting movement of the antenna
Excess buoyance:	10 kg
Drag:	Approximately 1 kilogram at 1 meter/second
Attachment:	Iron wire is fastened to the caudal scute of the turtle's carapace. A braided polypropylene line, 21 meters in length, is attached between the wire fastening and the float.
Power supply:	Rechargeable nickel-cadmium batteries to provide approximately 30 days of operation.
Transmission:	10-second cw pulse every 10 minutes followed by a 15-second pause, then three series of pulses of 13 ms to code X and Y magnetometer sensing and velocity.

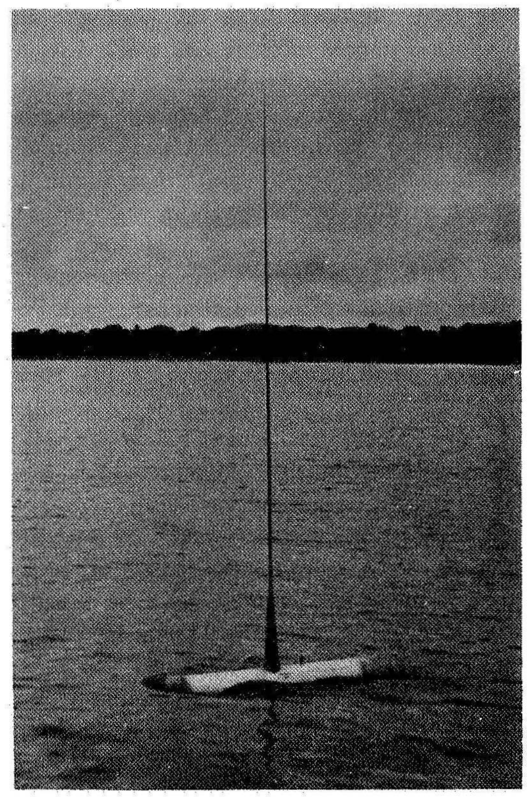

FIGURE 1. Transmitting float attached to a green sea turtle (not shown) to study path behavior during migration (summer 1970). The float transmits swimming speed and magnetic heading every 10 minutes.

A pilot experiment indicated satisfactory performance, with the exception that low speeds were not sensed. A venturi was placed over the paddlewheel velocity sensor to increase low-speed sensitivity. The minimum speed detectable with this feature was 0.27 meter/second.

EXPERIMENTAL RESULTS

Experiments 2 through 10 which are described below were conducted with the aid of a 16-meter motor vessel, the *Moderno*. Tur-

tles were displaced from the nesting beach various distances offshore and tracked by telemetry. The objectives were

(1) to investigate the "normal" behavior of a female turtle displaced away from the coast (nesting beach) and to establish the characteristics of its goal-directed homing ability;

(2) to investigate turtle path behavior under various weather conditions;

(3) to determine if, and under what conditions, small magnets might modify turtle path behavior.

The experiments which follow are numbered in chronological sequence. They refer to illustrations in the Appendix.

Experiment 1: Experiment 1 involved the release of an instrumented turtle from the nesting beach approximately 1 mile south of the entrance of the Tortuguero River into the Caribbean Sea (fig. 1). Investigators observed the behavior of the turtle and the float throughout the course of this experiment from a dugout boat (cayuca), approximately 10 m long and equipped with an outboard motor. The turtle swam outward from the beach at a comparatively rapid rate for approximately 30 min and then became quite inactive. The speed indicator on the radio float was not sensitive at these low speeds, and estimates of the actual swimming distance covering 10-min intervals were made by visual observation of the distance necessary to bring the cayuca back into the vicinity of the turtle. These distances are admittedly inaccurate. When they were significant, the time the boat was operated at a given motor speed was noted, and also a note with regard to whether the turtle was swimming, drifting or moving slowly was made in the record. If the turtle were moving significantly, the magnetic bearing data from the transmitter would correlate well with the actual heading of the turtle, but, during those periods when the turtle was inactive, the float at the end of a slack line very often took a heading somewhat different from that of the turtle. In addition to these interpretations of the turtle swimming behavior, the current along the beach was running at approximately 2 knots (4 km/hr). Periodic bearings were taken to various prominent terrain features such as Turtle Bogue Hill and the mountains approximately 28 km south of that hill.

The most significant observation was the fact that the turtle seemed to be inactive during the period when the sun was almost directly overhead. The experiment took place on September 4, 1970, at a time when the noon Sun position was 7° north of the equator. The latitude of Tortuguero is 10° 30′ north. Hence, for the period around noontime, it was not possible for the experimenter to orient with regard to the sun because of its near vertical position overhead. While sun compass orientation has not been demonstrated in *Chelonia mydas*, it must be strongly considered because of the importance of sun compass orientation to fish (ref. 4), birds (ref. 5), and possibly other migrating animals. The actual geographic movement with current covered some 24 km. The reconstruction of turtle path behavior is shown as though the turtle were swimming in still water.

Experiment 2: In this experiment we moved a turtle approximately 40 km offshore, beyond the edge of the continental shelf. By coincidence this turtle was the same one used earlier (tag number 6852) in September in experiment 1. She had been observed to nest successfully on two subsequent occasions and was captured after depositing eggs the second time. Nest locations were not dispersed more than 930 meters, so that one may conclude that the turtle was capable of remaining in the vicinity of the nesting beach in spite of the persistent current to the south-

east. The turtle was released at 1825 hr on the evening of October 2, just prior to a rain squall that obscured the sky. The turtle maintained an initial heading directly towards the nesting beach (west) although the beach itself was not visible and the sky was dark in that direction. The horizon to the east was clear. This turtle was remarkably consistent from the moment she was released until the float was lost from sight in the darkness in its direct heading toward Turtle Bogue Hill. Signals were obtained throughout the night and for the next 45 hrs. At approximately 2145 hr the rain squall broke and the stars became visible; within 20 min we noted a significant change in the direction from the telemetered path behavior data. During the morning of October 3, a second instrumented turtle (experiment 3) was released in the hope that the two turtles might take parallel paths in the same general direction. We soon found, however, that the turtles chose almost directly opposite headings and while we recovered signals from both transmitters during the day, we attempted to recapture the turtle heading out to sea. This attempt was unsuccessful, and we turned in pursuit of the turtle maintaining the westward heading. During the night of October 3, we heard a variation in the cw signal similar to those effected by handling the antenna, and soon thereafter the signal disappeared. The float was recovered several weeks later. The turtle had fouled the line in a drifting tree and submerged the antenna. The iron wire had eventually fatigued and released the turtle.

Experiment 3: This experiment shows the track of a turtle heading almost directly out to sea in a rather consistent manner. These turtles were released at the end of their nesting season, and it is quite possible that this turtle was returning to its feeding grounds somewhere in the Caribbean. As mentioned earlier, the float was not recovered.

Experiments 4 and 5: Experiments 4 and 5 were performed on the same turtle and are considered together because the experimental variable represented the presence of either a magnetic bar or a brass bar attached to the plastron of the turtle. Figure 2 is a sketch of the magnet assembly. The unit was made from Plexiglas and arranged to hold a bar magnet at its center of gravity so that it could pivot or rotate in a single plane parallel to the underside of the turtle. The concept of the device was to use the spinning magnet to test whether a changing magnetic field would be more disruptive to a turtle than a steady magnetic field. However, in experiments 4 and 5 this unit was placed on the plastron in such a manner that the magnet, while being free to move, did not actually

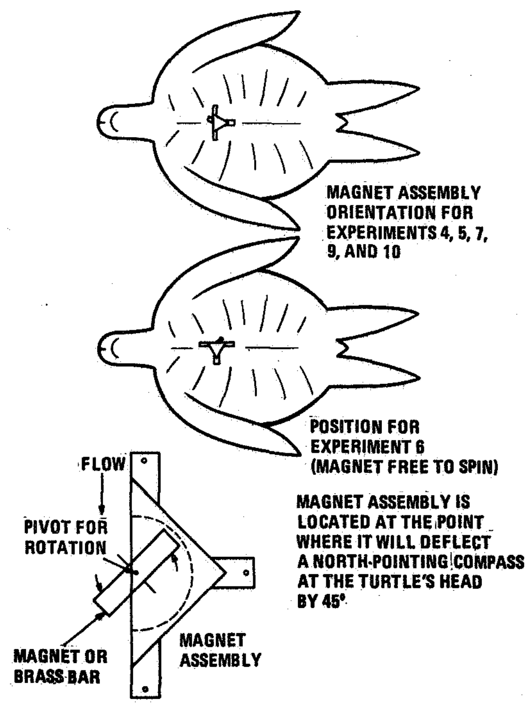

FIGURE 2. Details of attachment of magnets to the plastron of turtles.

rotate due to the flow of water past the attachment. The sketch shows this configuration for these experiments.

Experiment 5 was undertaken under similar conditions as experiment 4 with the exception that a brass bar of approximately equal size and weight replaced the magnetic bar. On both days the sun was visible and the weather was generally clear. Experiment 5 shows what we consider to be the normal heading toward the beach of a turtle displaced off the continental shelf. Experiment 4 appears to be a rather confused behavior pattern in comparison to the path reconstruction in experiment 5.

Experiment 6: This experiment was actually conducted in two parts and was intended to investigate the effect of a magnet on turtle path behavior during the hours of darkness. In this case the spinning magnet was placed in such a manner that the current passing by the underside of the plastron caused the magnet to spin rapidly. The turtle was released at 1450 hr some 37 km east of the beach beyond the continental shelf. The turtle was initially instrumented with the brass bar in place of the spinning magnet. Its path is shown for the period from 1450 hr to 1740 hr in a generally westerly direction after an initial escape circle to the east. After dark the turtle was recaptured and the magnetic bar was put in place of the brass bar on the turtle's plastron, still in such a way as to allow the current to spin it rapidly as the turtle swam. The float was also equipped at this time with a paddlewheel which produced a brief flash of light during each revolution. The turtle was released at 1745 hr and the flashing light was followed visually for a brief period of time. Suddenly, however, in the darkness the light ceased to flash at the same time the *Moderno* crossed a current boundary, noted by a heavy collection of sargassum plant and debris. We have assumed that the turtle also crossed this boundary and that the paddlewheel was fouled in the floating debris. The radio transmitter continued to report heading and velocity throughout the night. The track for the initial 2 hours showed a predominantly southerly heading. Then the track turned generally westward and eventually somewhat northwest during the next 2 days.

Early in the morning of the third day the turtle float was relocated by radio direction finding techniques and the turtle recovered near Limon, some 110 km southwest of the release point. The turtle experienced a strong southeast current during this time. At the time the turtle was recovered, the flasher was working in good order and the float was also performing as designed. The float had been out of visual contact since its release until actual recovery approximately 57 hr later. The turtle was found in a reef area which is known by turtle hunters as a place where turtles are likely to be found. We have tentatively concluded that while the spinning magnet may have been responsible for disrupting the initial orientation of the turtle, it soon crossed over the well defined edge of the continental shelf and either disregarded the spinning magnet influence in favor of other guidance cues, or, if in fact it was sensitive to the earth's magnetic field, then the earth's magnetic field may have been distinguishable in spite of the rapidly changing field of the spinning magnet.

Experiment 7: This experiment was conducted within 2.8 km of the coast northeast of the port of Limon. In this case, the magnet was attached to the plastron in a fixed position; that is, it was not allowed to pivot but was tied rigidly in place so that the north magnetic pole was initially on the left side of the turtle. After 2 hr of data in which the turtle maintained a rather well defined steady bearing to the northwest against the current,

the turtle was recaptured and the magnet pole shifted so that the north pole was on the right side of the turtle. The turtle was released at 1125 hr in the morning and within an hour thereafter found a submerged reef. We therefore feel that this experiment was not valid in terms of the magnet as an experimental variable. It further supports our conviction that when water depths are low, that is, when the turtle has the bottom available, it uses reference to the available cues in preference to magnetic guidance.

Experiment 8: Experiment 8 was conducted on October 17. Its objective was to investigate the effect of the hauling in of a turtle on its path under the conditions where no other experimental variables are presented. The turtle was released at 1327 hr and maintained a general heading slightly north of west. At 1527 hr the turtle was recovered and again released. The path clearly demonstrates the initial escape behavior and the ability of the turtle to recover its desired heading within some 30 min after release.

Experiment 9: This experiment took place on October 18. Its objective was to test the effect of the continental shelf on a turtle equipped with a magnet in a fixed position on the plastron. The starting position for this experiment was 18.5 km off the coast where the depth was approximately 24 meters. The turtle was equipped initially with the magnetic bar and released at 0918 hr. The turtle maintained a heading to the northwest and was recovered at 1128 hr. The magnetic bar was then replaced with a brass bar and the turtle released at 1138 hr. After the initial 20 min, the path became almost parallel to the previous path. We therefore conclude from this experiment that the magnet did not have an effect on orientation at this distance from shore.

Experiment 10: Experiment 10 involved the same turtle as experiment 9, which had not demonstrated modification of path behavior by a fixed magnet on its plastron. We moved this turtle approximately 40 km from the coast. The turtle was released at 1549 hr and the reproduction of the path indicates a shift in general direction of 90° between the average direction of a path in experiment 9. This result reinforces our conviction that if sensing of the Earth's magnetic field is important to turtle orientation, then it is of primary value in water depth in excess of 180 meters.

DISCUSSION

The experiments reported above need to be replicated many more times before we can be sure that the experimental variables are those we believe them to be. From the work performed so far we can formulate the following conclusions:

(1) The green turtle can be counted on to maintain a reasonably constant heading (goal directed homing) when released in the sea, which might be characteristic of that individual but at least can be expected to be consistent. This suggests that the green sea turtle, with adequate instrumentation to reconstruct path behavior, is an excellent subject for the investigation of marine animal navigation theory.

(2) In the vicinity of Tortuguero there exists the possibility that turtles locate the region of their nesting beaches by olfactory cues. The experiments described above tend to weaken this hypothesis since in all of the cases where the turtles were displaced 37 km to sea they were introduced into water whose deep blue coloring identified it clearly as part of the Gulf Stream (the Mosquito gulf current) in contrast to the pale green water found over the continental shelf in this region. The boundary line between these currents was defined visually by lines of sargas-

sum rafts which included floating logs and other debris. There seems to be little opportunity for the laws of diffusion to apply across such a well defined shear line with water on both sides of the shear line moving at quite different rates of flow. In our experiments we observed turtles crossing this shear line without any change in heading or speed. We therefore feel that the chemical content of the water itself is of little importance in orientation under these conditions.

(3) The effect of the placement of a magnet on a turtle produced a dramatic change in the path behavior of turtles released beyond the continental shelf. We are reluctant to state, however, that the experiments are statistically significant as independent events since we have only two observations. We are also reluctant to consider the 10-min intervals as independent observations. However, taking the paths as a whole there is a very strong conviction that in experiment 4, with the magnet free to pivot, the turtle's path can be classified as not oriented. The path in experiment 10 seems to produce an error of 90° that would be predicted from the placement of a magnet in a fixed position on the plastron. These observations are consistent with the hypothesis that turtles sense the Earth's magnetic field as a primary orientation cue in deep water.

Circuits used in the telemetry of turtle path behavior are shown in the Appendix.

POLAR BEAR INSTRUMENTATION

In the spring of 1970, the initial attempt was made to track polar bear on the polar ice cap north of Barrow, Alaska. Jack W. Lentfer had developed techniques of immobilizing bears using a helicopter (ref. 6) and had marked approximately 200 wild bears in previous seasons. Opportunity to work with these animals is restricted to spring months after the dark of the polar winter begins to disappear and before the sea ice recedes from the northern coastline of the Arctic region. Easy access to the ice cap is primarily limited to the range of light aircraft, and the instrumentation selected was based on the need to track radio tagged bears from the air. A VHF frequency, 148.5 MHZ, provided a short enough wavelength to allow the use of directional antennas mounted on a wing strut, and an electrically short collar antenna provided an omnidirectional signal for line-of-sight ranges greater than 185 km.

Figure 3 shows a radio tracking collar for polar bear prior to final sealing and waterproofing. The lower portion contains silver-cadmium rechargeable batteries for low tem-

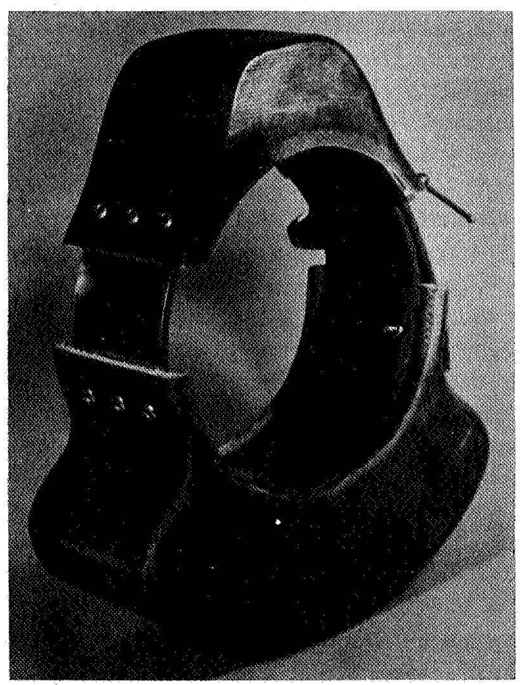

FIGURE 3. Polar bear radio collar during construction. Collar is made from machine belting, and electronic equipment is covered with fiberglass and embedded in foam.

perature operation to —60° F, and a small transmitter. The upper portion contains a low profile antenna. This antenna is approximately 2.5 cm in height and is embedded in low-loss dielectric foam to eliminate the possible loading effect of ice or sea water. The weight of the collar is approximately 2.3 kg.

Six transmitters were constructed and fastened to polar bears during the spring of 1970. One transmitter was removed when a bear was killed by hunters and was reused on a seventh bear. The longest track was approximately 150 km in a period of 23 days. Contact was made in this case on three occasions after release. Flying time was severely limited by weather conditions.

The greatest range for radio detection under field conditions was approximately 56 km. This is in contrast with tested ranges of 213 km with the transmitting collar placed on the ice and the receiver in an aircraft at 2440 meters above the ice. The lack of agreement may be due in part to the presence of ice pressure ridges, bear movements or body positions, and possible ducting effects due to the strong temperature inversion over the polar ice. In addition, subsequent testing indicated antenna detuning due to the high conductivity of polar bear fur after immersion in sea water.

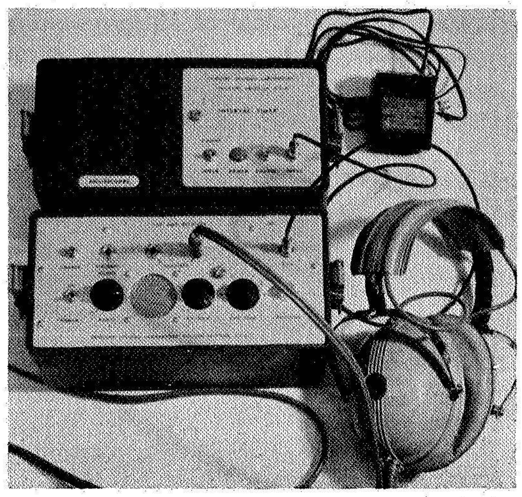

FIGURE 4. Tracking receiver for use in light aircraft. Interval timer allows for rapid identification of the pulse rate of an individual transmitter. All transmitters operate on same frequency since bears are dispersed.

FIGURE 5. Directional high-gain antenna for long-range detection of VHF signals.

The receiver system for use in the aircraft is shown in figure 4. The receiver is a narrowband (4 kHz) high-gain circuit optimized to receive and detect transmitter pulses of about 13 milliseconds in length. All transmitters operate on a single frequency and individual units are identified by their pulse period. The interval timer was used to help rapidly identify the pulse rate. Two receiving antennas were used: a commercial three-phase element yagi[3] for long-range unidirectional detection (fig. 5), and a dual half-wave antenna for detection of a null bearing by interferometry (fig. 6). Figure 7 shows a radio collar being fitted to the neck of a large female polar bear. The circuit for the transmitter is shown in figure 8.

It is too early in this program to interpret the significance of the tracking data obtained so far with polar bears in the vicinity of Point

[3] HyGain Model 23.

Barrow. The movement of all instrumented bears to the northeast during the spring seems to be part of an annual pattern, however, observed by hunters and Eskimos in previous years. One of the bears captured for instrumentation had been tagged 2 years earlier very close to the same location. Longer periods of observation at greater distances from Point Barrow will be required to establish a significant portion of the annual polar bear migration routes, if they exist.

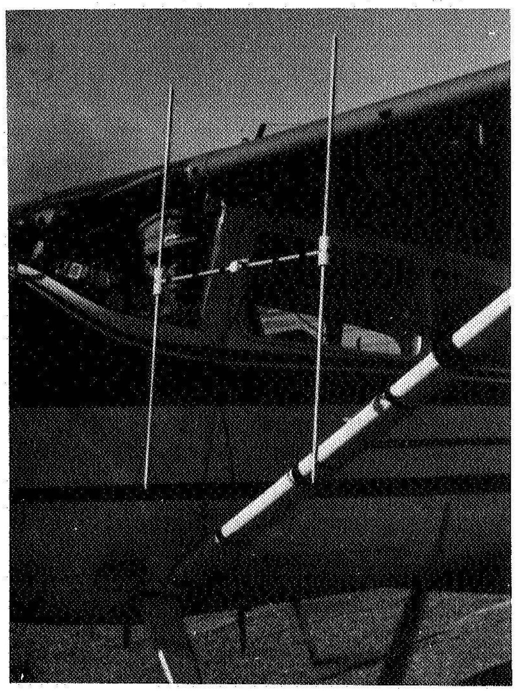

FIGURE 6. Interferometer antenna for detection of null bearings for accurate location of radio-tagged polar bears.

FIGURE 7. Radio collar being fitted to the neck of a large female polar bear.

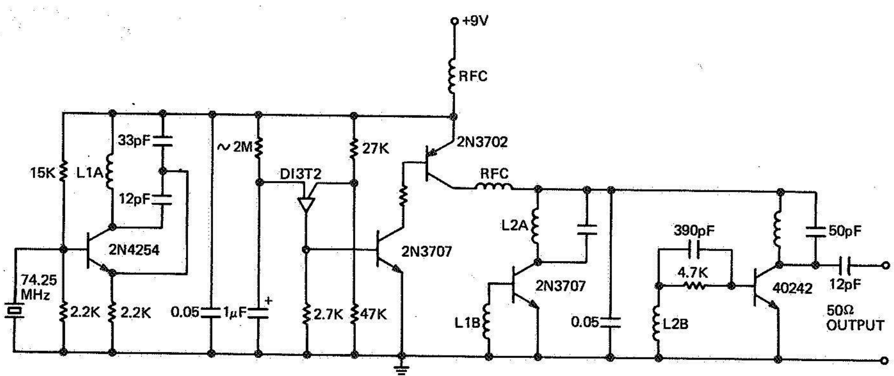

FIGURE 8. Circuit diagram for VHF (148.5 MHz) polar bear transmitter.

APPENDIX

TRACKING DATA AND CIRCUIT DIAGRAMS FOR TURTLE PATH TELEMETRY

Figures 9 through 18 show turtle tracking data by experiments referred to in the text. Figures 19 through 25 describe instrumentation used in these experiments.

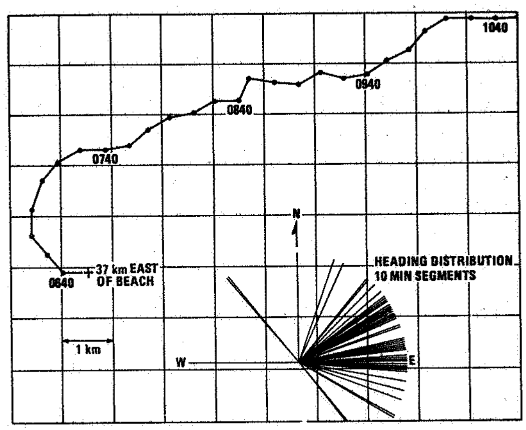

FIGURE 11. Experiment 3, October 3, 1970.

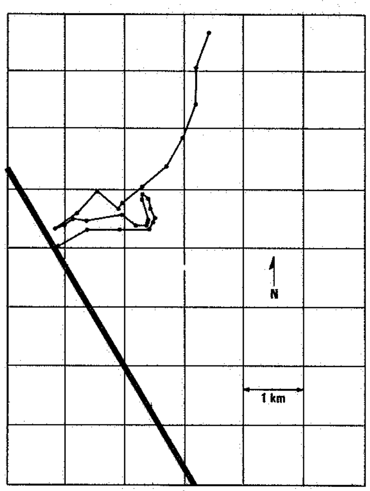

FIGURE 9. Experiment 1, September 4, 1970, without current.

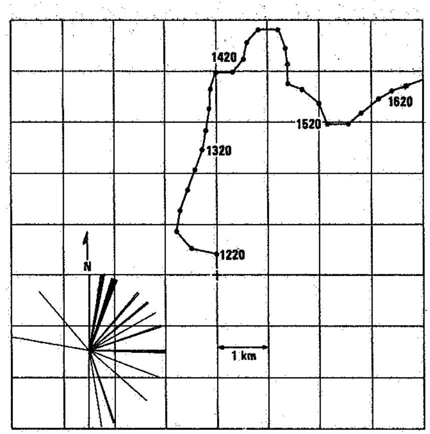

FIGURE 12. Experiment 4, October 9, 1970, fixed magnet.

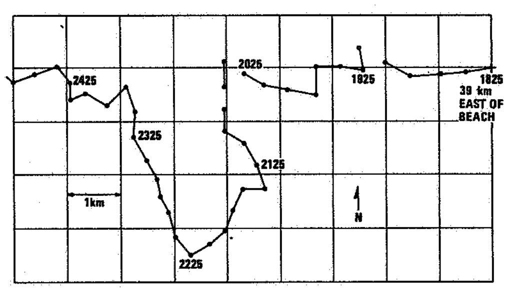

FIGURE 10. Experiment 2, October 2, 1970, sky obscure until 2145 hours.

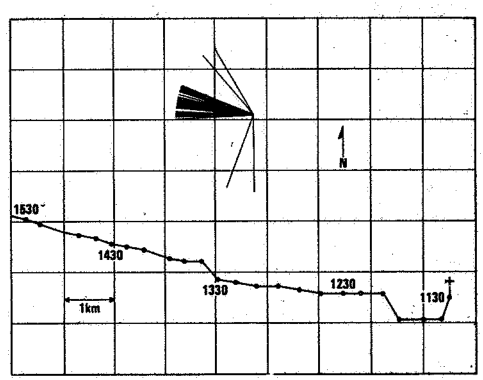

FIGURE 13. Experiment 5, October 10, 1970, brass bar.

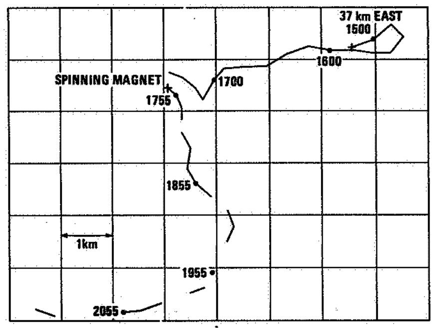

FIGURE 14. Experiment 6, October 12, 1970.

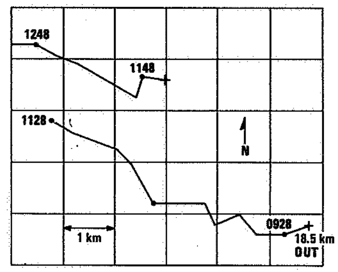

FIGURE 17. Experiment 9, October 18, 1970, fixed magnet.

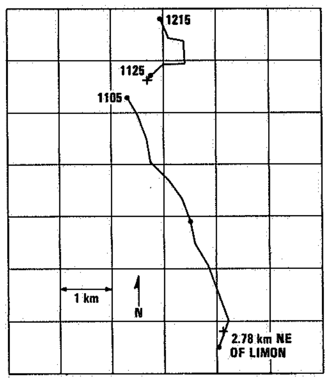

FIGURE 15. Experiment 7, October 15, 1970, fixed magnet.

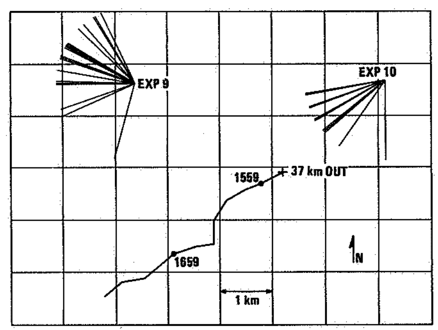

FIGURE 18. Experiment 10, October 18, 1970, fixed magnet

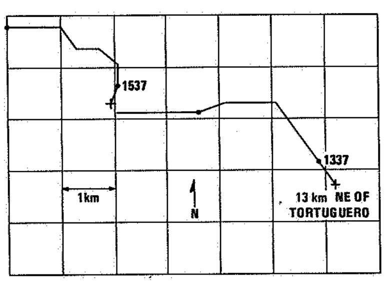

FIGURE 16. Experiment 8, October 17, 1970.

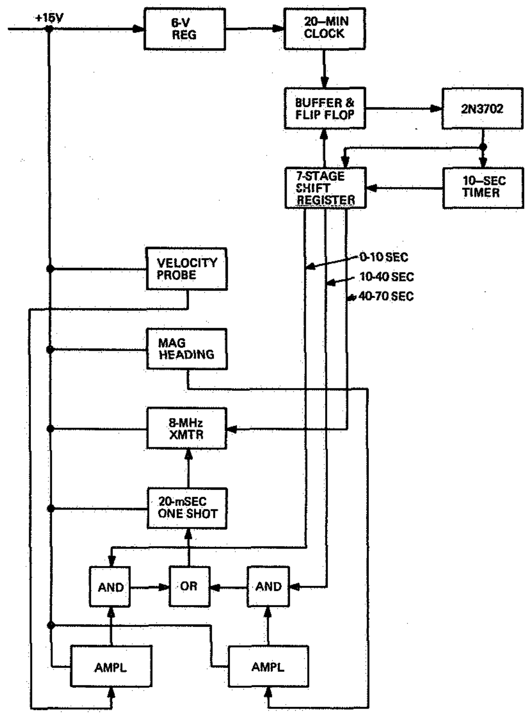

FIGURE 19. Block diagram of turtle float clock.

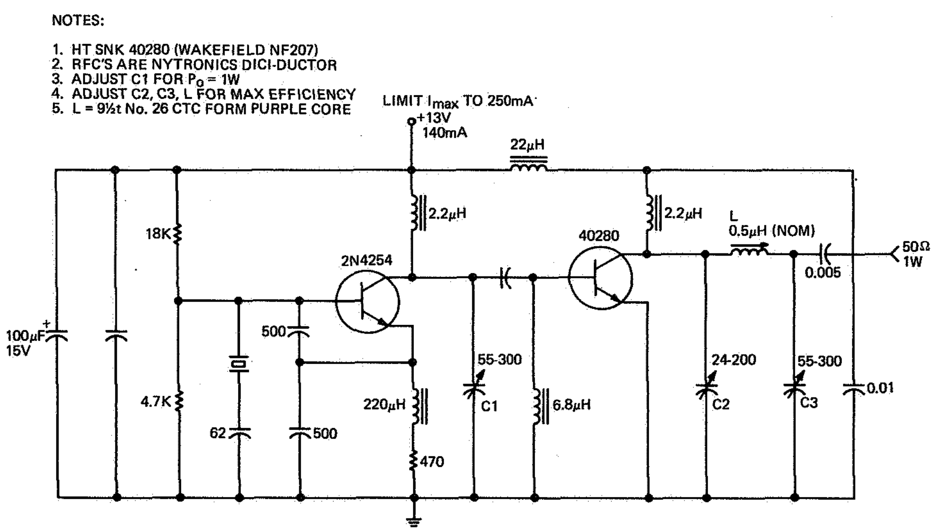

FIGURE 20. Circuit diagram of 8-MHz transmitter.

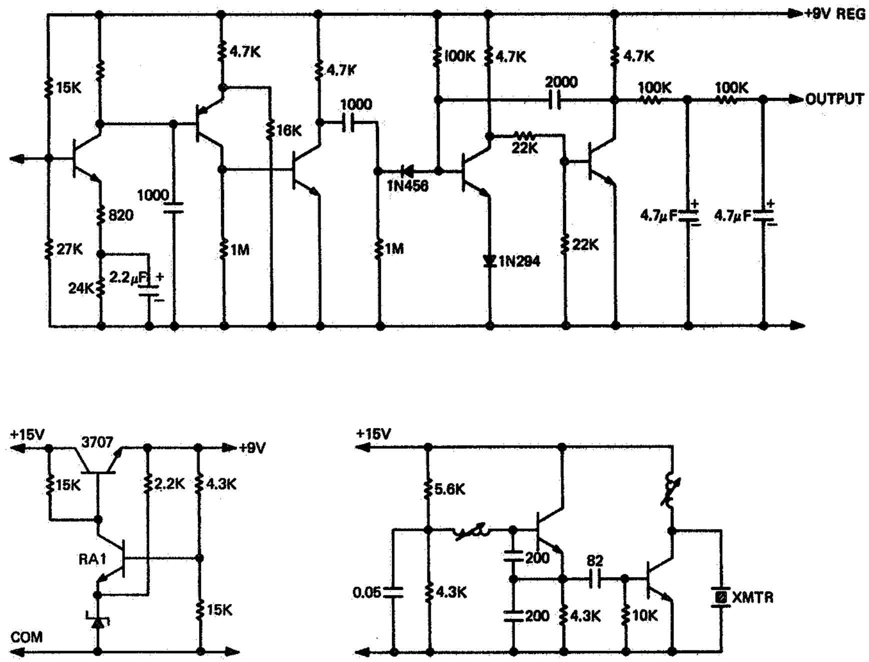

FIGURE 21. Circuit diagrams of Doppler velocity decoder, regulator, and transmitter.

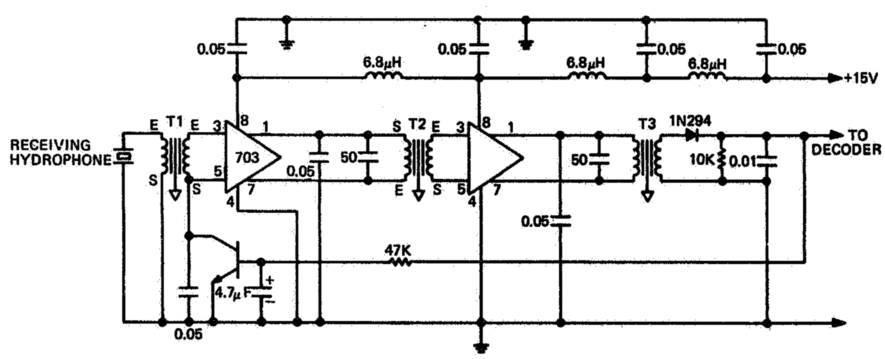

FIGURE 22. Circuit diagram of Doppler velocity-meter receiver.

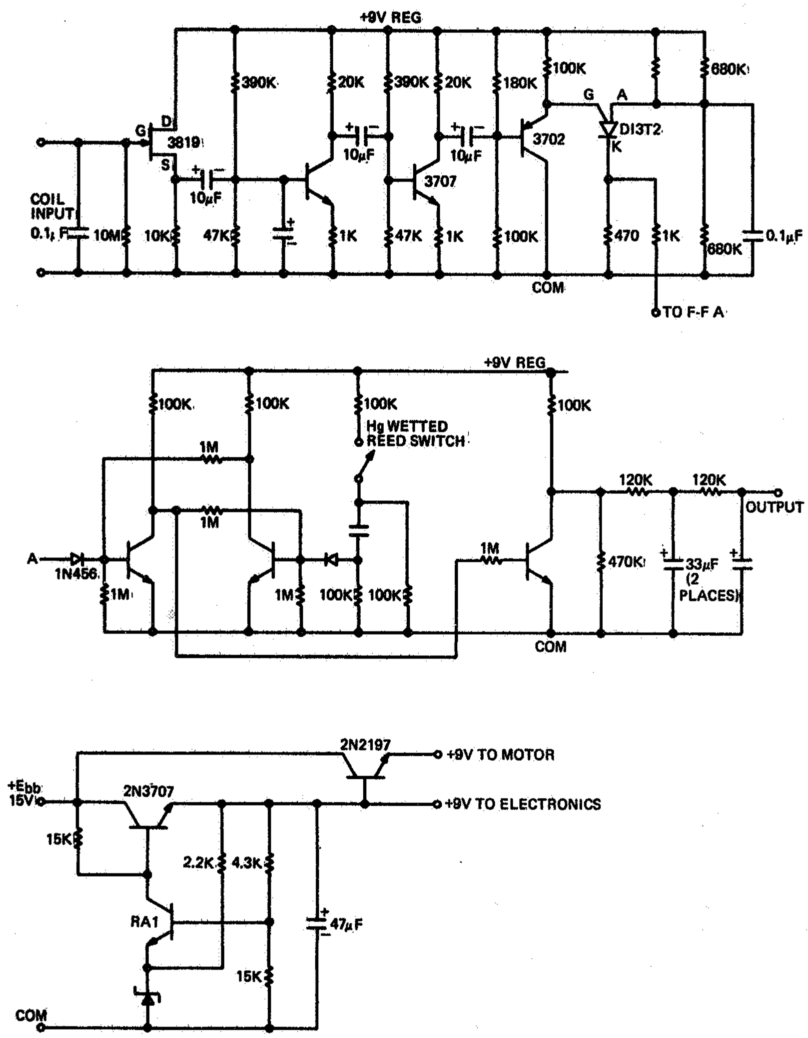

FIGURE 23. Circuit diagram of magnetometer compass.

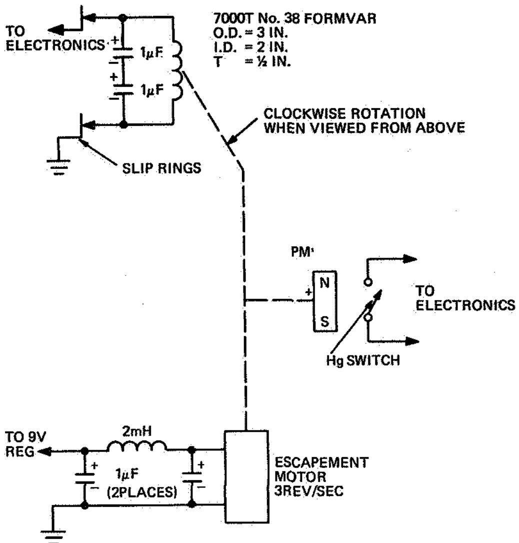

FIGURE 24. Schematic diagram of magnetometer compass.

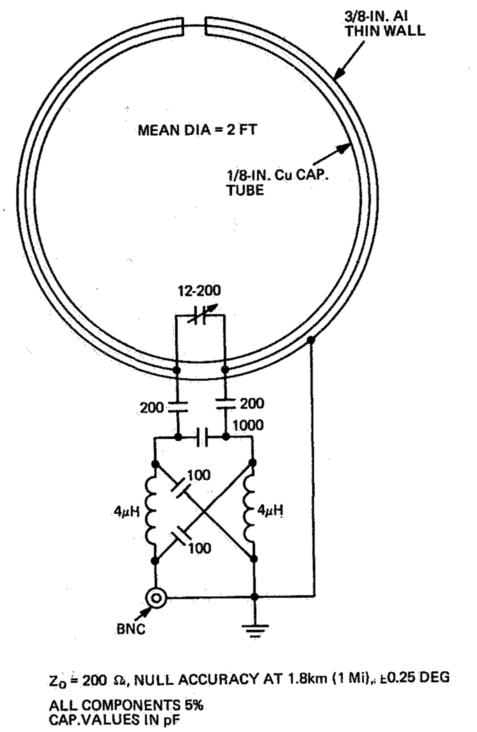

FIGURE 25. Schematic diagram of 8-MHz DF loop.

DISCUSSION

QUESTION: Would you please give more details concerning the release and heading of the turtles?

BALDWIN: Dr. Carr has described his hypothesis with regard to turtle navigation from the coast of South America to Ascension Island. Basically he has assumed that the westward drift of current past the island would carry a chemical cue discernible by turtles swimming against the westward drift to help them localize their goal—that is, Ascension Island. Dr. Carr, therefore, proposed displacing a turtle to the north of the island to avoid any guidance cues related to olfaction. Our telemetry system indicated that the turtle chose a heading directed toward Ascension immediately upon being launched from the ship, 187 km northwest of the island. However, we received data from the float for only 2 hours, and while this heading or azimuth data was consistently toward Ascension, we do not at this time feel that it is sufficiently convincing to rule out the olfactory orientation hypothesis for Ascension Island.

MACKAY: Do you think it would make any difference if the float were attached to a swivel above the center of mass of the turtle? Then, if there were a current, the torque would not keep twisting the turtle away from his chosen direction and into the current, as when the line is attached toward the end of the shell. It would seem that sort of a "crabbing" operation would be required to move in a preferred direction if the attachment was wrong.

BALDWIN: We have measured the drag of the transmitting float at approximately 910 grams of force at 0.9 meter per second velocity. This is certainly a minor drag for such a powerful swimmer as a mature green turtle. Furthermore, the attachment to the shell is made along a line running through the center of gravity of the turtle; there would, therefore, be no tendency for the float to modify the swimming direction of the turtle.

REFERENCES

1. Boyer, J. M.: Hula-Hoop Antenna—Coming Trend. Electronics, vol. 36, no. 2, Jan. 11, 1963, pp. 44–46.
2. Ingle, G. F.; and Baldwin, H. A.: A New Tool for Biotelemetry—Phase Coherent Tracking. Bioscience, vol. 18, no. 2, Feb. 1968, pp. 123–124.
3. Pellerin, C. J.; and Acuña, M. H.: A Miniature Two-axis Fluxgate Magnetometer. NASA TN D-5325, Jan. 1970, 23 pp.
4. Hasler, A. D.; Horrall, R. M.; Wisby, W. J.; and Braemer, W.: Sun Orientation and Homing in Fishes. Limn. and Oceano., vol. 3, no. 4, 1958, pp. 353–361.
5. Kramer, G.: Die Sonnenorientierung der Vogel. Verh. dt. Zool. Ges. Freiburg, 1952, pp. 72–84.
6. Lentfer, J. W.: Polar Bear Tagging in Alaska, 1968. The Polar Record, vol. 14, no. 91, 1969, pp. 459–462.